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NATURAL RESOURCES, CONSUMPTION, AND THE FUTURE: MANAGEMENT REQUIREMENTS

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I. INTRODUCTION AND SUMMARY

The subject of this paper is the impact of the Nation's population and level of per capita consumption on its natural resources through the year 2000, and the related management requirements imposed by existing and anticipated problems.

This complex subject involves interrelationships between (a) such physical factors as total natural resources and known materials reserves, population and population growth, and consumption--both U.S. and world--and (b) such policy factors as the impact of technology, economic profitability, and national and international policies on resources availability.

The relationship between resources, population, consumption, and the application of human technique has been put into a convenient equation by McKelvey: 1/

$$L = \frac{R \times E \times I}{P}, \text{ where}$$

L= society's average level of living measured by its useful consumption of goods and services;

R= society's useful consumption of all kinds of raw materials, including metals, nonmetals, water, soil minerals, biological produce, and so on;

E= society's useful consumption of all forms of energy;

I= society's useful consumption of all forms of ingenuity, including political, socioeconomic, and technological ingenuity; and

P= people who share in the total product.

1/ V.E. McKelvey. Mineral Resource Estimates and Public Policy. In Brobst, Donald A. and Walden P. Pratt, eds. United States Mineral Resources: Geological Survey Professional Paper 820. Washington, U.S. Govt. Print. Off., 1973: 9.

This equation is a useful illustration that per capita standard of living depends upon the availability of both natural resources and human ingenuity. Since ingenuity is essentially unquantifiable, the equation's predictive value is limited to qualitative estimates. However, the equation puts the basic relationship between resources and ingenuity into proper perspective and serves as a concise introduction to this paper.

Summary

1. There is a very important distinction between the world's stock of potentially recoverable resources, which is estimated to be very large in relation to anticipated world demand, and reserves, which are known natural resources which are economically recoverable with existing technology. Reserves generally represent only a small fraction of total resources and, for many materials, are smaller than anticipated world demand in the year 2000. However, reserves of most materials have increased continually over time, because of exploration and new technology, and are expected to continue to increase. When shortages develop and resource prices increase, previously known but uneconomical resources become economical to develop at the higher prices. Reserves (known and economically recoverable resources) are thereby increased.

2. U.S. population will probably increase by approximately 50 percent by the year 2000, and world population may double. Per capita consumption is also increasing dramatically, with U.S. per capita consumption demand possibly doubling by the year 2000. Per capita consumption in the rest of the world is also increasing significantly. Increases in population and per capita consumption contribute approximately equally to the expected several-fold increase in total world consumption demand

for materials in the year 2000 and beyond. Total U.S. materials consumption may double or triple by the year 2000 with similar trends in the rest of the world.

3. Perhaps the single most important factor in meeting the expected problems associated with limited materials availabilities throughout the rest of this century and beyond is human ingenuity. Many persons believe that technological ingenuity will ultimately solve or ameliorate the problems of providing sufficient amounts of economically recoverable materials. If so, this is a long-term solution. In the short term, the ingenuity of national political leaders will be increasingly tested as developed nations, like the United States, begin to rely more heavily on foreign reserves of materials. Increased international trade in materials, possible materials boycotts and cartels, and balance of payments considerations appear to be likely short-range problems with which the Congress and the Executive branch will be faced. "Third world" countries, many of which have large reserves of necessary materials, will also increase their materials demands and may also demand a more "equitable" share of world resources than they have received in the past.

4. The above factors suggest that national and international materials management is a useful concept for the world community to undertake. The most immediate priorities for materials management at the national political level would seem to be (1) increased knowledge about the world's stock of potentially recoverable materials, reserves, and materials consumption, (2) increased support for materials science and technology, and (3) the development of policies aimed at conserving, and

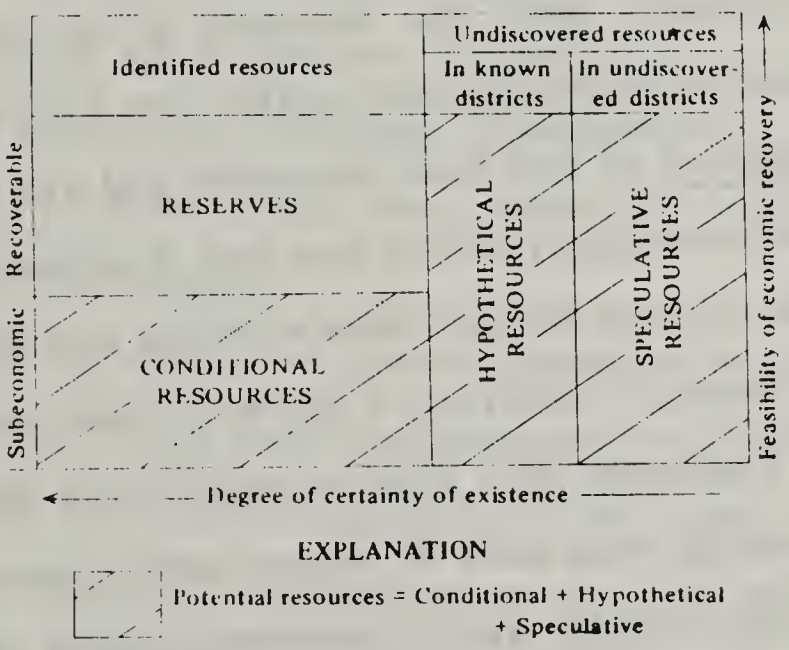
perhaps developing buffer stocks of, materials which are or may become scarce, or which are imported from politically uncertain supply sources.

II. NATURAL RESOURCES AND RESERVES

This section discusses the distinction between total natural resources and known reserves, excluding agriculture, and presents estimates of U.S. and world resources and reserves.

A useful schematic description of the relationship between reserves and total resources is shown below.

Figure 1. Schematic Relationship of Reserves to Total Resources



Source: Brobst, Donald A. and Walden P. Pratt. Introduction. In Brobst, Donald A. and Walden P. Pratt, eds. United States Mineral Resources. Geological Survey Professional Paper 820. Washington, U.S. Govt. Print. Off., 1973: 4.

Reserves are identified or known natural resources which are economically recoverable with existing technology. Conditional resources are known resources which are uneconomical to recover with existing technology. Undiscovered resources of varying degrees of certainty of existence make up the remainder of total resources. Although the terminology used in the literature of resource use is not uniform, the above terminology is both adequate and representative.

The relationships between the boxes comprising Figure 1 are not meant to portray actual natural resource quantities or percentages. Actual relationships between reserves and total resources are unknown, but estimates are available and will be discussed below. The relationships between reserves and total resources also vary from material to material.

An important fact in evaluating both reserves and resources is that both reserves and useful resources have increased steadily over time. Reserves are identified and economically recoverable resources. The amount of known and economically recoverable iron ore, for example, has increased dramatically since the beginning of the iron age. It is anticipated that more economically recoverable iron will be found in the future. Thus, reserves of iron have increased and are likely to continue to increase for some time, but for how long is unknown.

The total amount of iron ore and other elements and minerals in the earth is fixed, of course. However, of that total fixed amount (or total resources), useful resources have also increased over time. For example, before technology was used to reduce bauxite (aluminum oxide) to the metal aluminum, bauxite was a relatively useless resource and, until about 1860, petroleum was a relatively useless resource. Materials science and technology are likely to continue to increase the amounts of useful resources available to mankind in the future.

In brief, it is important to distinguish between:

-Total natural resources;

-Useful natural resources; and

-Reserves (known and economically recoverable natural resources).

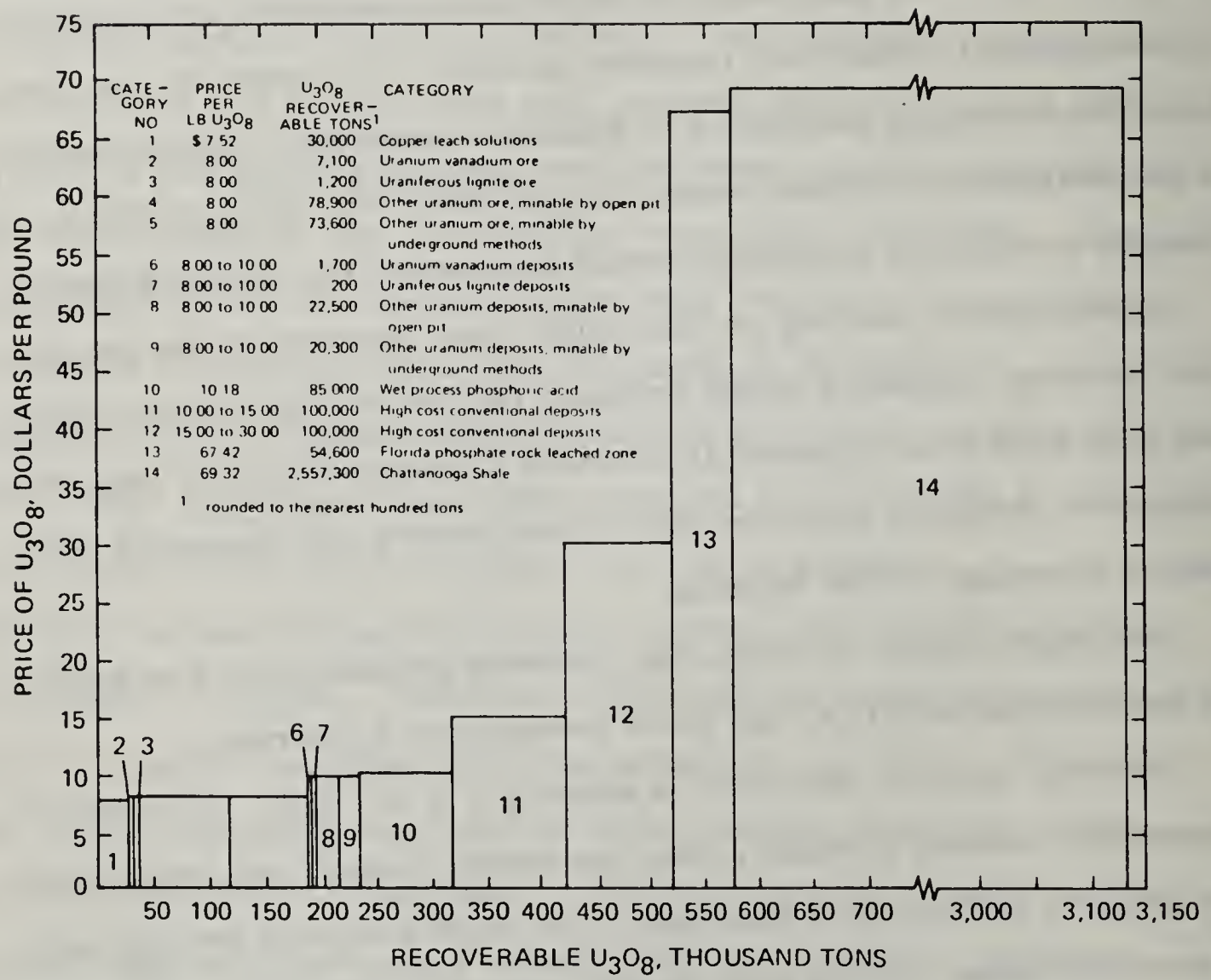
It is also important to realize that reserves account for only part of known resources. Many known resources are not economically recoverable with existing technology and are not considered to be reserves. As commodity prices increase and it becomes economically feasible to use previously uneconomical resources, reserves increase. The same is true when improved technology contributes to economic feasibility. As an example of the relationship between economics and reserves, the availability of uranium at different prices per pound is shown in the following figure.

Another factor bearing on knowledge about reserves is that the private resource companies which prospect for and develop resources may find it in their best commercial interests to understate or be less than diligent in recording reserves under their control for reasons of competitive advantage and tax benefits.

With these caveats in mind, the following paragraphs of this section set forth estimates of U.S. and world resources and reserves.

The total mass of the earth is about 6.5×10^{21} tons. In terms of foreseeable mineral recovery, only the crust, oceans, and atmosphere are likely to be sources of materials. The earth's average crustal depth is about ten miles and has about 24,000 quadrillion ($24,000 \times 10^{15}$) tons of materials while the oceans account for about 56 quadrillion (56×10^{15}) tons of dissolved minerals (56 percent sodium, 31 percent chlorine, 6.5 percent magnesium, 2.5 percent sulfur, 4 percent other) and the atmosphere accounts for about 5.6 quadrillion (5.6×10^{15}) tons of air (78 percent nitrogen, 21 percent oxygen, 1 percent argon). The crust is the earth's largest storehouse of potentially recoverable resources. Of the total abundance of resources in the crust (24,000 quadrillion tons),

Figure 2. Availability of Uranium


CATE-GORY NO
PRICE PER LB U_3O_8
U_3O_8 RECOVER-ABLE TONS[1]
CATEGORY
1 $ 7 52 30,000 Copper leach solutions
2 8 00 7,100 Uranium vanadium ore
3 8 00 1,200 Uraniferous lignite ore
4 8 00 78,900 Other uranium ore, minable by open pit
5 8 00 73,600 Other uranium ore, minable by underground methods
6 8 00 to 10 00 1,700 Uranium vanadium deposits
7 8 00 to 10 00 200 Uraniferous lignite deposits
8 8 00 to 10 00 22,500 Other uranium deposits, minable by open pit
9 8 00 to 10 00 20,300 Other uranium deposits, minable by underground methods
10 10 18 85,000 Wet process phosphoric acid
11 10 00 to 15 00 100,000 High cost conventional deposits
12 15 00 to 30 00 100,000 High cost conventional deposits
13 67 42 54,600 Florida phosphate rock leached zone
14 69 32 2,557,300 Chattanooga Shale
[1] rounded to the nearest hundred tons
PRICE OF U_3O_8, DOLLARS PER POUND
RECOVERABLE U_3O_8, THOUSAND TONS
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
50 100 150 200 250 300 350 400 450 500 550 600 650 700 3,000 3,100 3,150
1 2 3 6 7 8 9 10 11 12 13 14

AVAILABILITY DIAGRAM FOR URANIUM (EXPRESSED AS U_3O_8)

If the price of uranium is increased, greater tonnages of ore can be treated profitably to supply world requirements. Low-grade materials such as Florida phosphate deposits and the extensive Chattanooga shales could become commercial sources at a price. Source: "Availability of Uranium at Various Prices," U.S. Bureau of Mines Information Circular 8051.

Source: Materials Needs and the Environment Today and Tomorrow: Final Report of the National Commission on Materials Policy. Washington, U.S. Govt. Print. Off., June 1973: 4B-6.

perhaps about 40 trillion (40×10^{12}) tons, or approximately one millionth of total crustal abundance, is potentially recoverable at current levels of knowledge and technology. 2/ And about 75 percent of this amount is oxygen, silicon, and their compounds.

The approximate percentages of the major elements of the earth's crust are shown in the table on the following page.

Assuming that 10 trillion (10×10^{12}) tons approximates the total recoverable resource potential of the earth's crust at current levels of knowledge and technology, excluding oxygen, silicon, and their compounds which account for about 30 trillion tons, Table 2 suggests relationships between U. S. and world reserves and the currently estimated recoverable potential of some resources.

In summarizing the discussion of resources and reserves, there are three facts to keep in mind:

- Reserves (known economically recoverable resources) represent only a small fraction (generally minuscule) of potentially recoverable resources (see Table 2);

- The estimated figure for total potentially recoverable crustal resources (at current levels of knowledge and technology) represents only about one millionth of estimated total crustal abundance; and

- Current knowledge of the amounts of both reserves and total resources is quite limited.

2/ The figure of 40 trillion tons to represent the earth's total potentially recoverable resources is an estimate based upon the table of abundances, reserves, and resources found in Erickson, Ralph L. Crustal Abundance of Elements, and Mineral Reserves and Resources. In Brobst, Donald A. and Walden P. Pratt, eds. United States Mineral Resources: Geological Survey Professional Paper 820. Washington, U. S. Govt. Print. Off., 1973: 22-23. Most of the quantitative data used in this paper and elsewhere in the literature on resources and reserves generally represent only approximations and should not be considered to be precise.

Table 1. Percent Abundance of Major Crustal Elements

Oxygen	46.60	percent
Silicon	27.72	
Aluminum	8.13	
Iron	5.00	
Calcium	3.63	
Sodium	2.83	
Potassium	2.59	
Magnesium	2.09	
Subtotal	98.59	
Titanium	.44	
Hydrogen	.14	
Phosphorous	.12	
Manganese	.10	
Subtotal	99.39	
Sulfur	.05	
Carbon	.03	
Chlorine	.03	
Rubidium	.03	
Fluorine	.03	
Strontium	.03	
Barium	.03	
Zirconium	.02	
Chromium	.02	
Vanadium	.02	
Zinc	.01	
Nickel	.01	
Copper	.01	
Tungsten	.01	
Lithium	.01	
Total	99.73	percent

Note: The remaining 61 naturally occurring elements account for about .25 percent of the earth's crust.

Source: Derived from Weast, Robert C. ed. Handbook of Chemistry and Physics, Forty-Eighth Edition. Cleveland, The Chemical Rubber Company, 1967: F-135.

Table 2. United States and World Recoverable Resource Potential and Reserves

	World		United States	
	Recoverable Resource Potential	Reserves	Recoverable Resource Potential	Reserves
	(billion (10^9) tons)		(billion (10^9) tons)	
Aluminum	3,519	1.160	203	.008
Iron	2,035	87	118	1.800
Titanium	225	.117	13	.025
Phosphorus	51	15	2.94	.931
Manganese	42	.630	2.45	.001
Fluorine	20	.035	1.15	.005
Barium	17	.076	.98	.031
Chromium	3	.696	.189	.002
Vanadium	5	.010	.294	.0001

Source: Erickson, Ralph L. Crustal Abundance of Elements, and Mineral Reserves and Resources. In Brobst, Donald A. and Walden P. Pratt, eds. United States Mineral Resources: Geological Survey Professional Paper 820. Washington, U.S. Govt. Print. Off., 1973: 22-23.

What these facts imply in regard to the availability of resources for the future is that (1) human ingenuity is perhaps the most important aspect of resource recovery and (2) knowledge about resources and reserves should be greatly increased.

III. RESOURCE CONSUMPTION

This section discusses total and per capita resource consumption and consumption demand in the United States and the world through the year 2000 and beyond.

Resource consumption is a function of total population and consumption per capita. U.S. population is currently about 210 million. It will probably increase to about 300 million by the year 2000. This growth represents a one percent per year population increase.

World population is currently about 3.6 billion. Many sources estimate that world population will be about seven billion by the year 2000. 3/ This represents about a two percent population growth rate for the earth as a whole. Some parts of the world, particularly the developing nations, are increasing at even faster rates.

In terms of resource consumption per capita, the United States leads the world. With only about six percent of the world's population, the United States uses about 33 percent of the world's mineral resources 4/ and about 35 percent of the world's energy. 5/ During the last 30 years, the United States has used more minerals and mineral fuels than have all the people of the world previously. 6/

3/ See, for example, Frejka, Tomas. The Prospects for a Stationary World Population, Scientific American, v. 228, March 1973: 15-23.

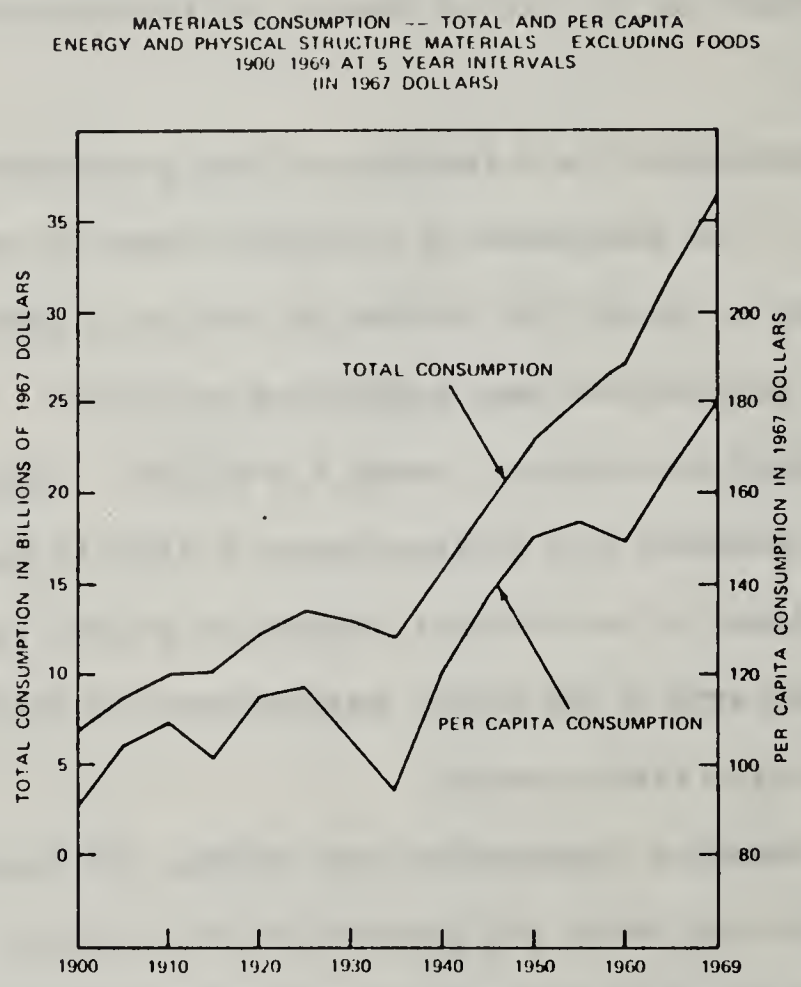
4/ Hayes, Earl T. U.S. Minerals Supply, Outlook, and Trends. In U.S. Congress. Senate. Committee on Public Works. Problems and Issues of a National Materials Policy. 91st Congress, 2d Session. December 1970. Washington, U.S. Govt. Print. Off., 1970: 50.

5/ U.S. Congress. Joint Economic Committee. The Energy Outlook for the 1980's. 93d Congress, 1st Session. December 17, 1973. Washington, U.S. Govt. Print. Off., 1973: 8.

6/ McKelvey, p. 11.

U.S. per capita materials consumption has increased significantly since 1900 as indicated by the dollar values shown in Figure 3, below:

Figure 3. Materials Consumption



Total consumption and per capita consumption of materials increased at similar rates in the United States during the first seventy years of the decade.

Source: Materials Needs and the Environment Today and Tomorrow: Final Report of the National Commission on Materials Policy. Washington, U.S. Govt. Print. Off., June 1973: 3-4.

Although the rate of increase may slow down somewhat, per capita consumption probably will continue to increase through the end of this century and beyond, perhaps doubling the 1973 level by the year 2000, assuming the continued economic availability of most materials. Per capita materials consumption in the rest of the developed world also probably will increase several fold. In the developing nations of South America, Africa, and Asia, with about two-thirds of the world's population, significant increases in per capita resource consumption are probable. The U.S. share of the world's materials consumption will probably continue to decrease from, for example, 50 percent of the world's mineral output in about 1952 and 33 percent currently 7/ to an even lower percentage in the years ahead.

Zero population growth has been suggested as a partial solution to increasing world demands for natural resources. However, it is likely to take decades before zero population growth, as a comprehensive world program, could be implemented through mass education and the use of widespread contraceptive techniques. Many moral, religious, cultural, and governmental issues also would have to be addressed before population control becomes feasible on a large scale. Consequently, many sources indicate that world population will probably double by the year 2000 (to about seven billion) and could double again (to about 15 billion) by 2100 before a stable world population is attained.

Thus, the world is faced with the possibility of a four-fold increase in population by about 2100 and rapidly increasing per capita materials consumption, particularly in the developing nations.

7/ Hayes, p. 50.

A few simple and rough calculations indicate possible relative materials consumption levels in the United States at the end of the Century.

U.S. population increase from 1973 to 2000, about 1.5 times

U.S. per capita consumption increase from 1973 to 2000, about 2 times

Total U.S. consumption increase from 1973 to 2000, 2 x 1.5 = about 3 times

In the rest of the developed world, a similar three-fold increase in consumption demand could be expected by the year 2000. In the developing two-thirds of the world, there will probably be a two-fold increase in consumption demand just due to population increase. Any increase in per capita consumption which the developing nations could manage would increase their total consumption demand that much more.

Both population and per capita consumption are exponentially increasing quantities in the world today. In the United States and other developed nations, per capita resource consumption appears to be increasing at a greater rate than population, while in the developing nations, the reverse may be true. However, both the growth in population and in per capita consumption demand appear to be problems of approximately equal magnitude, that is, they contribute approximately equally (on an order-of-magnitude basis) to the world's demand for natural resources. In short, population and per capita consumption demand appear to be the two sides of the same coin of increasing total consumption.

Of the two major factors of population and per capita consumption demand, population would appear to be the more critical factor in ensuring long-term resource availability. Theoretically, population could continue to increase until agricultural resources failed to keep up, while per capita

consumption is likely to ultimately level off since human beings have a limited capacity to use material resources, even though the limit may be at a relatively high level. It has been estimated that world agricultural production using known technology theoretically could be increased from four to eight times over the present level. 8/ However, it is likely that population control on a global scale would be instituted before the agricultural limits of population growth are reached. This control would probably occur because of generally decreasing food availabilities on a per capita basis and increasing food costs, regional famines, national aggressions caused by the internal pressures of overpopulation, decaying urban areas and decreasing quality of life due to overpopulation, and so on.

Thus, irrespective of the potential quantities of the earth's material resources, population is likely to stabilize at some small multiple (possibly three times) of the present population of the earth, perhaps based upon the ultimate agricultural production capacity of the earth.

Although world per capita consumption of materials is also likely to level off, world per capita consumption, or at least world per capita consumption demand, can also be expected to increase several-fold (perhaps two to three times) during the remainder of the 20th century and into the 21st century.

In general, total world resource consumption will increase significantly to the year 2000 and beyond. With current knowledge, it is impossible to know with any degree of confidence just what the levels of total

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8/ How Far Can Man Push Nature in Search of Food? Conservation Foundation Letter, November 1973: 6. Also See U.S. Congress. House. Committee on Foreign Affairs. Subcommittee on National Security Policy and Scientific Developments. Beyond Malthus: The Food/People Equation. 92d Congress, 1st Session. October 1971. Washington, U.S. Govt. Print. Off., 1971. 96 p.

and per capita materials consumption are likely to be, or to know what total world reserves (known and economicallly recoverable resources) will be at that time. Because of the vast store of potentially recoverable resources, however, it appears that in the year 2000 there would be total reserves sufficient to meet total consumption demand, although perhaps, at considerably higher real costs.

For the United States, the Final Report of the National Commission on Materials Policy contains probable cumulative primary mineral demand figures from 1971 to 2000 (as estimated by the U.S. Bureau of Mines in 1973) and estimated reserves at 1971 prices. These statistics are reproduced in Table 3 on the following two pages. Although the table is useful, neither "probable cumulative primary mineral demand 1971-2000," "reserves at 1971 prices," "identified resources," nor "hypothetical resources" should be considered to be firm data. Demand and resources are estimates, and reserves are likely to continue to increase due to changes in economic factors and technology and because new resources will be identified.

A comparison of Table 3 data with Table 2 data (see page 11) provides some interesting insights. If it is assumed that U.S. "probable cumulative primary mineral demand in 1971-2000" (Table 3) will account for approximately 25 percent of world demand over that period, it can be seen that for the materials listed in Table 2, such world demand would represent only very small percentages of "recoverable resource potential," generally less than one percent, with chromium being the highest of those listed at about 2.5 percent. While data analysis of this type is intriguing, data of materials resources, reserves, and consumption probably are not adequate at this time for deriving sound conclusions

Table 3 U.S. Reserves and resources of selected mineral commodities

Commodity	Units [1]	Probable cumulative primary mineral demand 1971-2000[2]	Reserves at 1971 prices[2]	Identified resources[3]	Hypothetical resources[4]
Aluminum	Million S.T.	370	13	Very large	KDI
Antimony	Thousand S.T.	822	110	Small	Small
Arsenic	Thousand S.T.	800	700	–	–
Asbestos	Million S.T.	43	9	Small	Insignificant
Barium	Million S.T.	31	45	Very large	Very large
Beryllium	Thousand S.T.	28	28	Very large	Huge
Bismuth	Million lb.	81	10	–	–
Boron	Million S.T.	5	40	Very large	Huge
Bromine	Billion lb.	12	17	Huge	Huge
Calcium	Billion S.T.	5	Adequate	Very large	Huge
Cadmium	Million lb.	560	264	–	–
Cesium	Thousand lb.	350	–	–	–
Chlorine	Million S.T.	645	Adequate	Huge	Huge
Chromium	Million S.T.	19	–	Insignificant	Insignificant
Clay	Billion S.T.	3	Adequate	Large	Very large
Coal	Billion S.T.	21	Adequate	Huge	Huge
Cobalt	Million lb.	540	56	–	–
Columbium	Million lb.	288	–	–	–
Construction Stone					
Crushed	Billion S.T.	41	Adequate	Large	KDI
Dimension	Million S.T.	79	Adequate	Large	KDI
Copper	Million S.T.	93	81	Large	Large
Diatomite	Million S.T.	29	40	Huge	KDI
Feldspar	Million L.T.	38	500	Huge	Huge
Fluorine	Million S.T.	39	6	Small	Small
Gallium	Thousand kg.	281	Adequate	–	–
Germanium	Thousand lb.	1,600	900	–	–
Gold	Million tr. oz.	293	82	Large	KDI
Graphite	Million S.T.	2	–	Very large	KDI
Gypsum	Million S.T.	726	350	Huge	Huge
Hafnium	Short Tons	1,280	Adequate	–	–
Indium	Million tr. oz.	19	11	–	–
Iodine	Million lb.	269	225	Very large	Huge
Iron	Billion S.T.	3	2	Very large	Huge
Kyanite	Million S.T.	9	15	Huge	Huge
Lead	Million S.T.	34	17	Large	Moderate
Limestone & Dolomite	–	–	–	Large	KDI
Lithium	Thousand S.T.	183	2,767	Huge	Huge
Magnesium	Million S.T.	52	Adequate	Huge	Huge
Manganese	Million S.T.	50	–	Large	KDI
Mercury	Thousand flasks [5]	1,730	75	Small	KDI
Mica, sheet	Million lb.	62	–	Insignificant	Very large
Mica, scrap and flakes	Million S.T.	7	250	Huge	Huge
Molybdenum	Billion lb.	3	6	Huge	Huge
Natural Gas	Trillion cu. ft.	1,098	279	Moderate	Large
Nickel	Billion lb.	14	– [6]	Large	KDI
Nitrogen	Million S.T.	1,018	Adequate	Huge	Huge

Table 3 -- Continued

Commodity	Units [1]	Probable cumulative primary mineral demand 1971-2000 [2]	Reserves at 1971 prices [2]	Identified resources [3]	Hypothetical resources [4]
Peat	Million S.T.	43	Adequate	Huge	KDI
Petroleum	Billion bbls.	276	38	Large	Large
Phosphorus	Million S.T.	208	39	Very large	Huge
Platinum	Million tr. oz.	16	1	Moderate	Large
Potassium	Million S.T.	216	50	Very large	Huge
Pumice	Million S.T.	208	200	–	–
Rare earths	Thousand S.T.	452	5,045	Huge	KDI
Rhenium	Thousand lb.	360	400	–	–
Sodium	Million S.T.	1,160	Adequate	Huge	Huge
Sand & Gravel	Billion S.T.	54	Adequate	Large	KDI
Scandium	kg.	554	Adequate	–	–
Silver	Million tr. oz.	4,400	1,300	Moderate	Large
Strontium	Thousand S.T.	771	–	Huge	Huge
Sulfur	Million L.T.	514	75	Huge	Huge
Talc	Million S.T.	52	150	Very large	Huge
Thorium	Thousand S.T.	21	2	Very large	KDI
Titanium	Million S.T.	32	33	Very large	Very large
Tungsten	Million lb.	1,000	175	Moderate	Moderate
Uranium	Thousand S.T.	1,240	130	Large	Large
Vanadium	Thousand S.T.	471	115	Very large	KDI
Zinc	Million S.T.	67	30	Very large	Very large
Zirconium	Million S.T.	4	4	Large	KDI

NOTES AND DEFINITIONS

[1] S.T. = Short Tons
L.T. = Long Tons
lb. = pounds
tr. oz. = troy ounces
kg. = kilograms
bbls = 42 gallons

[2] As estimated by U.S. Bureau of Mines, 1973.

[3] Identified Resources are defined as including reserves and materials other than reserves which are essentially well known as to location, extent and grade and which may be exploitable in the future under more favorable economic conditions or with improvements in technology.

[4] Hypothetical resources are undiscovered, but geologically predictable, deposits of materials similar to identified resources.

[5] 76 lb. Flasks

[6] Less than one unit.

RESOURCE APPRAISAL TERMS

Huge		Domestic resources (of the category shown) are greater than ten times the minimum anticipated cumulative demand (MACD) between the years 1971 and 2000.
Very large		Domestic resources are two to ten times the MACD.
Large		Domestic resources are approximately 75 percent to twice the MACD.
Moderate	–	Domestic resources are approximately 35 percent to 75 percent of the MACD.
Small	–	Domestic resources are approximately 10 percent to 35 percent of the MACD.
Insignificant	–	Domestic resources are less than 10 percent of the MACD.
KDI	–	(Known Data Insufficient) Resources not estimated because of insufficient geological knowledge of surface or subsurface area.
	–	Dashes indicate data not available.

Source: Materials Needs and the Environment Today and Tomorrow: Final Report of the National Commission on Materials Policy. Washington, U.S. Govt. Print. Off., June 1973: 4B-8 and 4B-9.

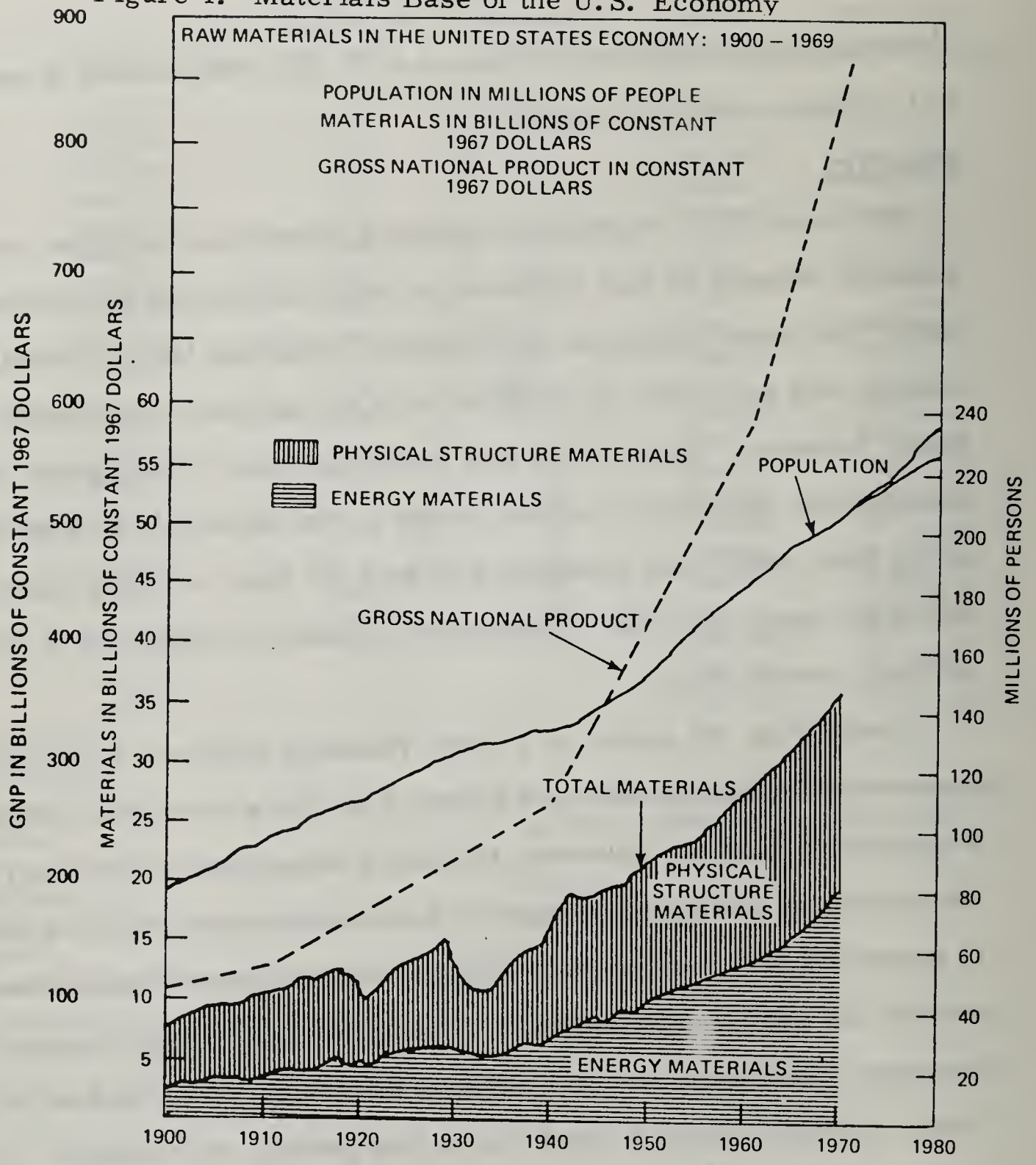
about the current and future status of U.S. and world stocks of materials and probable materials demand.

Summary

The state of the knowledge concerning resources, reserves, and consumption demand is that estimates of these factors can be made and are useful, but total resources are unknown; reserves have continually increased and are likely to continue to do so because of increasing knowledge, economic factors, and new technology; and consumption demand is extremely difficult to predict except to the extent that through the end of the 20th century and probably well into the 21st century at least, both world per capita and total consumption demand for resources is likely to increase several fold.

Considering the earth as a total resource system, it appears that most world resources will be adequate even for a many-fold increase in consumption demand. However, increased demand will undoubtedly mean temporary and localized shortages in some commodities until new sources of supply are developed or until abundant materials are developed as substitutes for scarce commodities. In addition, resources in general may increase significantly in cost, although historical trends to date indicate rather constant resource costs over a long period. For example, Figure 4 on the following page shows graphically the close relationship between total materials costs and population in the United States from 1900 to 1970. The rapidly increasing gross national product since about 1940 indicates the transformation of the United States from a goods producing and consuming nation to a services-oriented nation. However, the danger in projecting future relationships from past trends is that the underlying realities change. The period covered in Figure 4 was a period of

Figure 4. Materials Base of the U.S. Economy



MATERIALS BASE FOR A POST–INDUSTRIAL ECONOMY

As the United States evolved from a basic agricultural and manufacturing economy in the early decades of this century to a more mature service-oriented economy in recent decades, requirements and supplies of mineral materials kept pace with population growth despite wars and recessive periods. The faster rise of gross national product since 1940 reflects the increase in services and the amenities of life in the United States. Source: "Raw Materials in the United States Economy: 1900–1969," Bureau of Census, U.S. Department of Commerce; and Bureau of Mines, U.S. Department of the Interior.

Source: Materials Needs and the Environment Today and Tomorrow: Final Report of the National Commission on Materials Policy. Washington, U.S. Govt. Print. Off., June 1973: 2-5.

generally plentiful and relatively cheap resources in the United States. Recent and impending shortages in materials may significantly increase material costs over the short term. For example, rapidly increasing costs for petroleum may continue for many years until major new reserves of petroleum are found, if there are any, or until substitutes for petroleum (like shale oil and coal liquefaction) are commercially developed.

IV. TECHNOLOGY, ECONOMICS, AND NATIONAL AND INTERNATIONAL POLICIES

A brief review of the preceding two sections of this paper indicates that although the world's potentially recoverable resources are estimated to be very large, known economically recoverable reserves of some materials are small in relation to existing or anticipated consumption demand. The United States is turning increasingly to foreign, rather than domestic, reserves to meet its domestic requirements for many materials. The Appendix to this paper gives some indication of the United States' current dependence on imported materials.

What this situation means for the United States is that increasingly the Nation will have to rely upon technology and national and international policies to provide it with materials at economically acceptable costs. Even so, the costs of some, perhaps many, materials can be expected to increase over time. When costs of commodities become high enough, previously uneconomical known resources will be tapped and substitute materials will be developed. In short, the era of generally cheap and exploitable materials may well be at an end in the United States and the world. The developing two-thirds of the world will increasingly compete for, rather than merely supply, many of the materials that the United States will require. Being the world's richest country, the United States will no doubt be able to afford higher costs for materials and, as in many things, it will be the poorer countries that are likely to suffer disproportionately from increased materials costs.

Technology is looked upon by many persons as being the means for providing adequate supplies of materials to meet the world's increasing

requirements. There is evidence that technology is an exponentially increasing function in developed and technology-intensive societies. 9/ If this is true, technology can be expected to provide the techniques necessary to keep up with the world's increasing demand for materials, perhaps through that time when both world population and per capita consumption could be expected to stabilize at some (from now) relatively high level. In the field of energy, the ability of technology to provide rapidly increasing supplies is already manifest. It is anticipated that nuclear fusion of hydrogen from sea water will be possible in the 21st century, possibly by 2030. If fusion is actually developed as a safe energy source, it will provide an almost unlimited source of energy for the world.

It can be anticipated that the application of technology to materials problems will result in similar benefits in the future, but between now and then the world will have to make do with recovering materials with existing technology.

To buy time for technology to provide adequate amounts of materials at reasonable costs to meet the expected several-fold increase in world demand for materials, there is likely to be greater pressures on national legislatures and executives to develop workable national and international materials and materials-related policies. For example, to offset or ameliorate possible near-term national shortages in many materials, the Congress will probably be faced with major materials policy considerations in areas like:

9/ Starr, Chauncey and Richard Rudman. Parameters of Technological Growth. Science, v. 182, October 26, 1973: 358-364.

-International trade;

-International assistance in materials development;

-Developing buffer stocks of potentially scarce materials;

-Incentives for the exploration and development of materials by commercial interests;

-Government-supported materials research and devleopment;

-Materials effectiveness, like recycling, reuse, improved engineering design, and materials conservation;

-Rationing; and

-National and international environmental aspects of materials recovery, use, and disposal.

All of these policy considerations deal with securing adequate sources for the rapidly increasing U.S. demand for materials. Because the United States has been the greatest, and sometimes profligate, user of the world's resources during the 20th century, there may be increasing international pressures, especially from the developing "third world," for assistance in developing world resources and for sharing them more equitably than in the past.

The factors discussed in this section suggest that human "ingenuity" may be the most important ingredient in developing U.S. and world material resources. In the long-term, technological ingenuity may provide the major solutions to the materials supply problem. Although this is possible, and even probable, the technological solution is not completely certain and is probably a long way off. Until then, national and international policy-makers must use their ingenuity in facing the many intricate problems associated with making the wisest use of the earth's limited supply of currently known resources.

What is certain is that there will be constraints upon the world supply of materials throughout the remainder of the 20th century. There will probably be periodic materials shortages, and materials costs are likely to rise. New reserves will be found and substitutes will be developed. Hopefully, materials science and technology will be supported to the extent required to provide a continual supply of materials for world development, through (1) the discovery of new reserves or entirely new uses of existing reserves of abundant materials and (2) the conservation and reuse of existing materials. To the extent that scientific and technological ingenuity is not used to solve the materials supply problem, it is safe to predict that the political ingenuity of national legislatures and executives will be called upon to develop policies on a wide range of materials-related issues for getting the most use out of the world's economically recoverable resources.

V. MANAGEMENT PROBLEMS

There is a wide range of problems related to the rational development of the natural resources of the United States and the world. The problems can be classified as international, economic, technological, political, and so on. This section will deal with problems that can be classified as management problems, that is, problems which involve the application of high-level decisionmaking, in this case specifically decisionmaking at the national political level.

The priorities of national decisionmakers concerned with materials policy might include:

-Increased knowledge concerning the earth's store of natural resources;

-Increased knowledge concerning probable per capita consumption trends in the United States and the world;

-The development of early warning systems to predict short-term materials shortages;

-Increased materials research and development efforts; and

-Research into possible alternatives to the Nation's and the world's limited reserves to conserve scarce materials.

In short, the most pressing management requirement in the field of materials policy is increased information about the basic parameters of materials supply and demand and additional research on resource discovery and recovery and materials effectiveness. Only when more is known about materials resources and use, can adequate long-range decisions be made on the national and international levels. In the meantime, management problems will probably include the resolution of short-term crises

like materials shortages and imbalances in international trade. To offset recurring shortages and imbalances in materials production and supply, a system of national and international buffer stocks could be developed for those materials which are, or are expected to be, in short supply, or which are imported from politically uncertain supply sources. Buffer stocks could provide a cushion against physical shortages of materials, against price fluctuations, and against supply disruptions caused by international political situations.

Through technology and intelligent management of the earth's resources, the earth may ultimately provide sufficient materials for a high quality of life for most of its inhabitants. However, political decision-makers cannot assume without some risk that this is the case. Perhaps a preferable working hypothesis would be that materials usage will outpace materials production if intelligent national and international materials management is not vigorously pursued. It appears that the most important aspects of improved materials management are (1) a significant increase in knowledge about the earth's store of potentially and economically recoverable resources, (2) increased support for materials science and technology, and (3) the development of policies aimed at conserving, and perhaps developing buffer stocks of, materials which are scarce, potentially scarce, or which are imported from politically uncertain supply sources.

APPENDIX UNITED STATES DEPENDENCE ON IMPORTED MATERIALS

Commodity	Present Cost of Imports ($billion)	Percent Dependence *	Major Import Sources **	
I. Materials Arranged According to the Present Cost of Imports (Column 2)				
1. Petroleum, including natural gas liquids	7.5	29-32	Canada	42%
			Venezuela	17
			Indonesia	7
			Nigeria	7
			Saudi Arabia	6
			Others	21
				100%
2. Iron and steel	3.4	20	Europe	45%
			Japan	40
			Canada	9
			Others	6
				100%
Iron ore	.5	28	Canada	50%
	3.9		Venezuela	31
			Liberia	6
			Others	13
				100%
3. Aluminum metal	.3	10	Canada	76%
			Others	24
				100%
Bauxite	.4	90-96	Jamaica	54%
	.7		Surinam	23
			Guyana	7
			Others	16
				100%
4. Gold	.7	61-80	Canada	51%
			Switzerland	24
			Burma	9
			United Kingdom	3
			Others	13
				100%
5. Nickel	.5	74-90	Canada	82%
			Norway	8
			Others	10
				100%

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* Published figures for "percent dependence" vary according to whether U.S. imports are measured against U.S. primary (new) production of materials or against primary production plus scrap, and perhaps for other reasons. Consequently, the figures of Column 3 are sometimes given as a range, like "29-32" percent dependence for petroleum.

** Based on 1969-1972 average data.

Continued

	Commodity	Present Cost of Imports ($billion)	Percent Dependence	Major Import Sources	
6.	Zinc	.5	52-68	Canada	68%
				Mexico	24
				Peru	8
					100%
7.	Copper	.4	15-18	Canada	31%
				Peru	27
				Chile	22
				Rep. South Africa	6
				Others	14
					100%
8.	Natural gas	.4	4-9	Canada	97%
				Mexico	3
					100%
9.	Silver	.3	44-70	Canada	58%
				Peru	20
				Mexico	8
				Others	14
					100%
10.	Tin	.3	77-100	Malaysia	64%
				Thailand	27
				Others	9
					100%
11.	Chromium	.1	100	U.S.S.R.	32%
				Rep. South Africa	30
				Turkey	18
				Phillipines	14
				Others	6
					100%
12.	Cobalt	.1	98-100	Zaire	45%
				Belgium & Lux.	29
				Norway	8
				Canada	6
				Others	12
					100%
13.	Fluorine	.1	77-87	Mexico	77%
				Spain	12
				Italy	6
				Others	5
					100%

Continued

Commodity	Present Cost of Imports ($billion)	Percent Dependence	Major Import Sources	
14. Lead	.1	26-36	Canada	29%
			Peru	21
			Australia	21
			Mexico	12
			Others	17
				100%
15. Manganese	.1	95-98	Gabon	35%
			Brazil	33
			Rep. South Africa	7
			Zaire	7
			Others	18
				100%
16. Platinum	.1	99-100	United Kingdom	39%
			U.S.S.R.	32
			Rep. South Africa	12
			Others	17
				100%

II. Materials Whose Present Costs of Imports Are Less Than $0.1 Billion, Arranged According to Percent Dependence (Column 3)

17.	Cesium	Less Than $0.1 Billion	100	Pollucite: Canada & Africa	Most
				Cesium Compounds:	
				West Germany	87%
				Netherlands	8
				Others	5
					100%
18.	Columbium	ditto	67-100	Brazil	62%
				Canada	16
				Nigeria	14
				Others	8
					100%
19.	Hafnium	ditto	100	France	65%
				Japan	8
				Others	27
					100%
20.	Indium	ditto	100	Canada	44%
				U.S.S.R.	14
				Others	42
					100%

Continued

	Commodity	Present Cost of Imports ($billion)	Percent Dependence	Major Import Sources	
21.	Rhodium	Less Than $0.1 Billion	100	United Kingdom U.S.S.R. Others	59% 15 26 100%
22.	Rubidium	ditto	100	Negligible imports	
23.	Scandium	ditto	100	Australia Canada Others	55% 40 5 100%
24.	Strontium	ditto	100	Mexico United Kingdom Spain	81% 12 7 100%
25.	Tantalum	ditto	97-100	Canada Brazil Zaire Others	30% 22 14 34 100%
26.	Titanium (Rutile)	ditto	86-100	Australia Sierra Leone	92% 8 100%
27.	Zirconium metal	ditto	100	Australia Others	96% 4 100%
28.	Corundum	ditto	100	Kenya	100%
29.	Mica sheet	ditto	100	India Brazil Malagasy Rep. Others	79% 14 3 4 100%
30.	Palladium	ditto	98	U.S.S.R. United Kingdom Rep. South Africa Others	51% 32 6 11 100%

Continued

	Commodity	Present Cost of Imports ($billion)	Percent Dependence	Major Import Sources	
31.	Graphite	Less Than $0.1 Billion	97	Mexico	76%
				Malagasy Rep.	9
				Norway	6
				Sri Lanka	5
				Others	4
					100%
32.	Antimony	ditto	65-95	Ore:	
				Rep. South Africa	51%
				Mexico	20
				Others	29
					100%
				Metal:	
				Mexico	18%
				Peoples Rep. China	16
				Others	66
					100%
33.	Arsenic	ditto	90	Sweden	43%
				Mexico	40
				France	15
				Others	2
					100%
34.	Iodine	ditto	86	Japan	72%
				Chile	28
					100%
35.	Asbestos	ditto	84-85	Canada	96%
				Rep. South Africa	3
				Others	1
					100%
36.	Mercury	ditto	58-83	Canada	59%
				Mexico	17
				Spain	8
				Italy	5
				Others	11
					100%
37.	Yttrium	ditto	73	Australia	53%
				Malaysia	44
				Others	3
					100%

Continued

	Commodity	Present Cost of Imports ($billion)	Percent Dependence	Major Import Sources	
38.	Gallium	Less Than $0.1 Billion	64	Switzerland	72%
				United Kingdom	4
				West Germany	4
				Others	20
					100%
39.	Bismuth	ditto	62-75	Peru	34%
				Mexico	29
				Japan	11
				Canada	9
				Others	17
					100%
40.	Cadmium	ditto	25-62	Japan	23%
				Canada	22
				Australia	15
				Peru	12
				Others	28
					100%
41.	Thorium	ditto	60	Australia	53%
				Malaysia	44
				Others	3
					100%
42.	Beryllium ore	ditto	53	Brazil	64%
				Rep. South Africa	13
				Argentina	7
				Others	16
					100%
43.	Potassium	ditto	45-60	Canada	94%
				Israel	2
				Others	4
					100%

Source: Department of the Interior, Bureau of Mines information as of February 1, 1974; andMaterials Needs and the Environment Today and Tomorrow: Final Report of the National Commission on Materials Policy. Washington, U.S. Govt. Print. Off., June 1973: 2-25.

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